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CHOOSING THE OVERALL SIZE OF THE STRATEGIC PETROLEUM RESERVE.(U)
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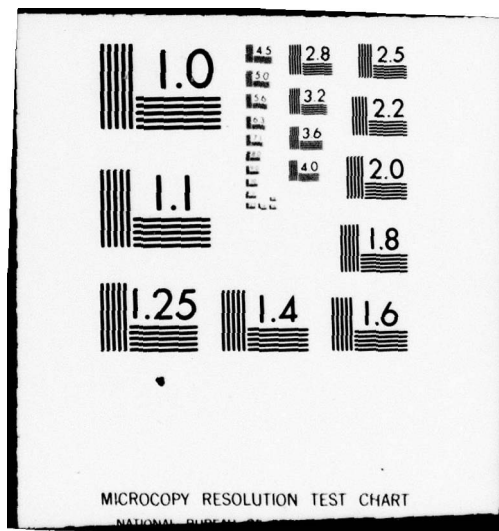
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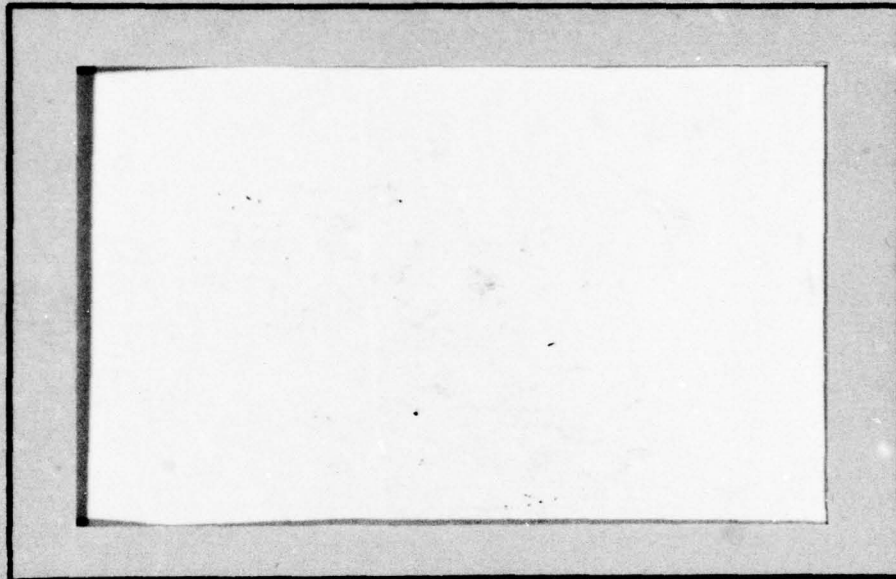


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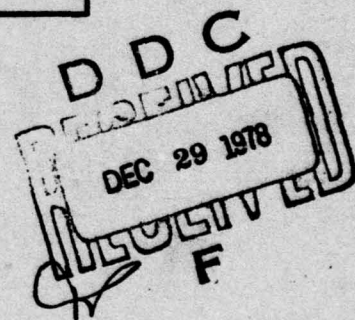
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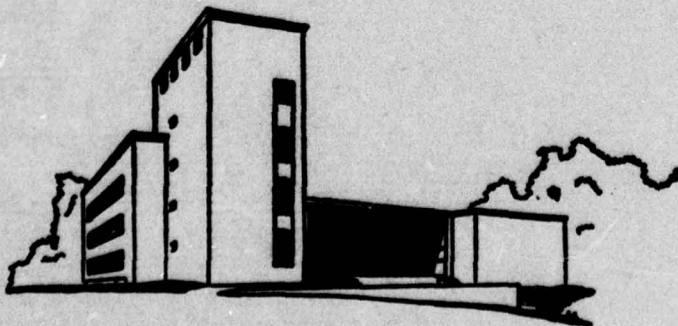
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10 by
Egon Balas

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Abstract

↙ The purpose of the Strategic Petroleum Reserve (SPR) is to diminish U.S. vulnerability to, as well as to offer protection against, possible future oil embargoes. This paper formulates the problem of determining the optimal size of SPR as a parametric bimatrix game between the U.S. and its potential opponent. The strategies of the opponent are embargoes of various intensities and lengths, including of course the no embargo option. The strategies of the U.S. are various ways of using the reserve. The size of the reserve itself is a parameter present in both payoff functions. Solving the game for the relevant reserve sizes yields interesting conclusions on the desirable size of the reserve, as well as on U.S. drawdown policies in case of an embargo. The crucial element in the game-theoretic approach is that, unlike the traditional cost-benefit analysis, it fully captures the embargo-deterrent effect of an appropriate Strategic Petroleum Reserve. ↗

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CHOOSING THE OVERALL SIZE
OF THE STRATEGIC PETROLEUM RESERVE *

by

Egon Balas
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1. Introduction and Background

In 1976 I spent the fall semester on leave from my University, as a visiting operations research analyst with the Federal Energy Administration in Washington. At first I got interested in the Strategic Petroleum Reserve (SPR), because the optimal location of storage sites seemed to be a problem where my skills could be helpful. I very soon discovered, however, that the concern for the location of storage facilities was entirely overshadowed by the more basic preoccupation with the pending decision on the overall size of the reserve, and so I decided to concentrate my efforts on the problem of choosing the optimal size of the SPR. My findings were summarized in a memorandum dated October 28, 1976, published later in the Congressional Hearings [3]. This paper is a slightly modified and expanded version of that memorandum.

*Paper presented at the Energy Policy Modeling Conference, Vancouver, B.C., May 1978.

From mid-October 1973 till mid-March 1974, the U.S. was the object of an oil embargo on the part of the OAPEC (Organization of Arab Petroleum Exporting Countries, a subunit of OPEC). Right before the embargo, U.S. petroleum consumption was the equivalent of about 19 MMB/day (million barrels per day), of which about 7 MMB/day was being covered by imports. Roughly 45% of these imports, i.e., slightly over 3 MMB/day, were coming from the OAPEC countries. This supply interruption and the subsequent quadrupling of the price of oil had a severe impact on the U.S. and world economy. In the U.S., the GNP loss directly ascribed to the embargo was estimated to have been between \$10-20 billion [1, p. 288].

The embargo has alerted U.S. policy makers and the public at large to the vulnerability that our high degree of dependence on oil imports entails. As a result, in December 1975, Congress passed the Energy Policy and Conservation Act (Public Law 94-163), which provides for the creation of a Strategic Petroleum Reserve, meant to reduce the vulnerability of the U.S. to petroleum supply interruptions and to alleviate the impact of such disruptions, should they occur. The law provides for an Early Storage Reserve of at least 150 MMB to be put in place by December 1978, and for a total Strategic Petroleum Reserve of up to 1,000 MMB. It further specifies that by December 1982 the reserve should reach a level corresponding to the volume of imports during the 3 consecutive highest import months of 1974-1975, subsequently determined to be about 500 MMB. Finally, it calls on the Administration to submit a SPR Plan by December 1976.

Several alternative technologies for storing oil were studied in 1974-1975, and storage in underground salt domes was found to be by far the most convenient solution economically, environmentally, as well as from

the standpoint of security. The vast salt formations in the southern states offer more than sufficient potential storage sites. Creating an underground storage facility in a salt dome (leaching the cavity and building the connecting pipeline network) costs about \$1.5/barrel of oil, a modest amount in comparison with the cost of the oil itself (about \$13/barrel).

In order to make a recommendation on the overall size of the reserve as part of the SPR Plan that it was preparing for Congress, the Federal Energy Administration has conducted several studies of the efficiency of various reserve sizes. The basic approach used was cost-benefit analysis.

2. The Limitations of Cost-Benefit Analysis

If we assume that an embargo will take place some time during the next 15 years, a good measure of the efficiency of SPR is the total cost to the U.S. of the embargo, as a function of the reserve size. This total cost can be measured by the sum of (a) the cost of the reserve, and (b) the GNP loss caused by the petroleum shortfall that the reserve cannot replace. The cost of the reserve is an increasing linear function of the size of the reserve, whereas the GNP loss can be approximated by a quadratic function of the percentage petroleum shortfall, where the latter decreases linearly with the reserve size. As a result, the total cost is a convex function of the reserve size, which has a minimum. Figure 1 illustrates a case where the minimum total cost occurs for a SPR of 500 MMB.

This kind of analysis yields a perfectly adequate measure of the usefulness of the reserve in its impact-reducing capacity; but it fails to assess its value as an embargo-deterrent, since it assumes the occurrence of the embargo independently of the existence and size of SPR.

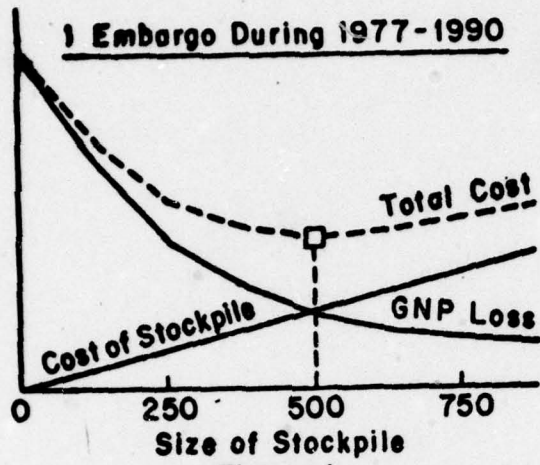


Figure 1

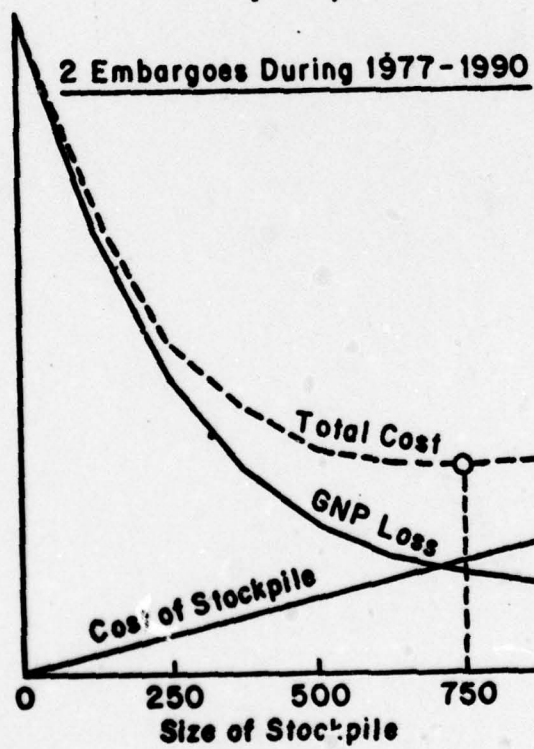


Figure 2

Furthermore, since the history of the last 30 years in the Middle East has produced at least one embargo-prone conflict every 7 years, assuming two embargoes during the next 15 years is at least as justified as assuming one. Making this assumption doubles the size of the GNP loss used in the calculation, while it leaves unchanged the total cost of the stockpile. The outcome for the example of Figure 1 is that the point of minimum total cost shifts from a stockpile of 500 MMB to one of 750 MMB, as shown in Figure 2.

3. A Parametric Bimatrix Game

Since any embargo is the result of a conflict, and since conflict situations are best analyzed by the mathematical discipline called game theory, the proper analytical tool that suggests itself for determining the optimal size of the SPR, is a game theoretical model, namely a parametric bimatrix game. Such an approach, unlike the traditional cost-benefit analysis, addresses simultaneously both aspects of the SPR, i.e., its embargo-deterrent as well as its impact-reducing aspects. Rather than assuming the occurrence of an embargo to be an event independent of the existence and size of the SPR, this approach treats the embargoes of various lengths and intensities as possible outcomes of the game, whose probability of occurrence is a function of, among other things, the size of the U.S. petroleum reserve.

In a bimatrix game there are two players, each of whom has several strategies at his disposal. The objectives pursued by the two players are expressed by their respective payoff functions, given by two $m \times n$ matrices, $A = (a_{ij})$ and $B = (b_{ij})$. The interpretation of the latter is that if player 1 uses strategy i and player 2 uses strategy j , then player 1 gains

a_{ij} units and player 2 gains b_{ij} units (here "gain" means loss whenever a_{ij} or b_{ij} is negative). A mixed strategy x for player 1 is a non-negative m -vector whose components sum to one, and whose interpretation is that player 1 uses strategy i with probability x_i . A mixed strategy y for player 2 is a n -vector defined and interpreted in an analogous fashion. An equilibrium point (or solution) is a pair of mixed strategies (\bar{x}, \bar{y}) , such that $\bar{x}A\bar{y} \geq xA\bar{y}$ for all strategies x available to player 1, and $\bar{x}B\bar{y} \geq \bar{x}By$ for all strategies y available to player 2. The essential characteristic of an equilibrium point is that it maximizes each player's gain (minimizes each player's loss), under the assumption that his opponent plays the game in a best possible way. Every bimatrix game has a solution.

To formulate the problem of the optimal size of the SPR as a parametric bimatrix game, we assume, based on the experience of the past 30 years, that during the next 15 years there will be two conflict situations in the Middle East. A conflict situation is defined as one in which the OAPEC countries, or some of them, wish to pressure the U.S. into some action alien to its political goals. Such a situation may, but need not, lead to an embargo. Note that this is a considerably weaker assumption than the one used earlier. For each conflict situation, we formulate a bimatrix game in which the two players are the OAPEC and the U.S. The U.S. has a petroleum stockpile whose size is a parameter in the game, i.e., we wish to solve the game for all relevant stockpile sizes, and determine that range of stockpile sizes, for which the solutions are most convenient. The strategies available to the OAPEC are the embargoes of varying length and intensity, including, of course, the "no embargo" option. At some point one may also wish to consider

strategies of a different type, e.g., a politically motivated price-hike. The strategies available to the U.S. are the various possible drawdown policies (uniform, exponential with different rates, etc.).

The objective of the U.S. is to minimize the total cost, i.e., the sum of the GNP loss caused by the OAPEC action, and the cost of the stockpile over the whole period considered. Hence, the U.S. payoff function (to be maximized) is the negative of this sum. It depends, of course, on the value of the parameter expressing the size of the stockpile.

The objective of the OAPEC is more difficult to assess and to quantify in a way which makes sense. Since this is the most delicate part of formulating the game, it will be discussed in some detail. A conflict situation was earlier defined as one in which the OAPEC wants to blackmail the U.S. into some action contrary to U.S. policies. Thus, the objective of the OAPEC is to exert pressure on the U.S. It seems reasonable to assume that the pressure exerted by some OAPEC action increases with the damage caused to the U.S. On the other hand, actions of the type considered here also carry some cost to the OAPEC. We will, therefore, assume that the pay-off function of the OAPEC is of the form $f = g - h$, where g is a function of the GNP loss inflicted upon the U.S. via the embargo, and h is a function of the cutback in petroleum production which accompanies the embargo. As to the shape of these functions, since conflict situations are triggered by, and related to, events which usually have a rather rapid course, it is natural to perceive an embargo as a blackmailing device whose objective is to obtain some action of considerable urgency. It, therefore, seems reasonable to assume that the function g , while increasing with the size of the U.S. GNP loss, decreases

with the length of the period over which the loss is spread. In other words, we assume that a GNP loss inflicted upon the U.S. in the first quarter of the embargo is of "full value" to the OAPC, a loss of the same magnitude inflicted in the second quarter is of somewhat lesser value, etc.; and losses suffered by the U.S. a year later are of little if any value.

On the other hand, the loss suffered by the OAPC as a consequence of a given petroleum production cutback (and of possible retaliatory action on the part of the U.S. and its allies) may be easy to bear at the beginning, in view of the sizeable surplus that these countries possess. As time goes by and the surplus is consumed, the loss becomes felt. It seems, therefore, reasonable to assume that the function h starts at a level close to 0 and increases slowly with both the size of the percentage cutback in petroleum production, and the length of time over which the cutback is imposed.

The functions f , g and h are illustrated in Figure 3, which represents them as functions of time (number of days), for a given stockpile size and petroleum cutback (both the cutback in daily petroleum production and the resulting daily GNP loss are assumed to be constant over time). The function g is equal to the GNP loss function in the first quarter, then asymptotically approaches the horizontal line. The function h is almost horizontal in the first quarter, then asymptotically approaches a line parallel to the petroleum cutback function. The resulting function $f = g - h$ is first increasing, then decreasing; and its maximum corresponds to the optimal (for the OAPC) length of the embargo, given its assumed intensity and the size of the U.S. stockpile.

One can, of course, argue about the correct numerical values for the coefficients defining the functions g and h , but it seems that there is little room for argument about the general shape of f , g and h , which reflects the basic features of the type of conflict situation considered here.

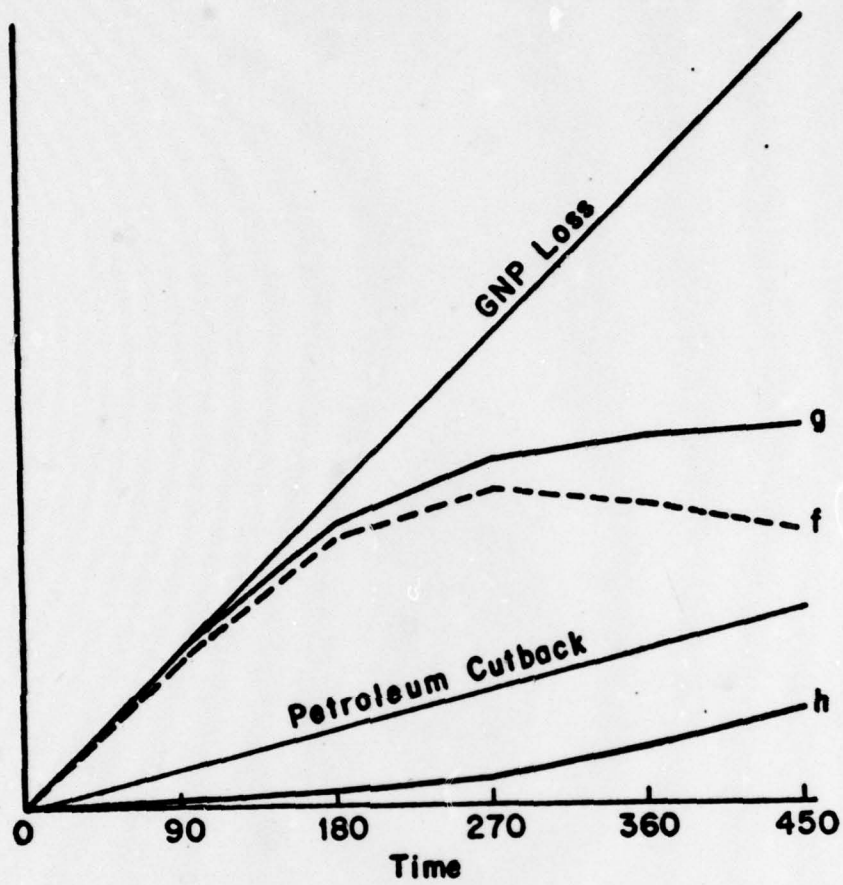


Figure 3

The model described above has several advantages. It takes a global view of the problem, i.e., it incorporates into the analysis all major aspects, including the embargo-deterrent effect of the stockpile. If solved for all relevant stockpile sizes, it yields not only an optimal size for the stockpile, but a probability distribution of the embargoes of varying length and intensity, for each stockpile size considered. Further, it produces optimal drawdown strategies for the various stockpile sizes.

The major difficulty with the model is that the solutions depend on the coefficients of the payoff function f about which little is known. The way to cope with this difficulty is to parametrize the coefficients of f and solve the game for the relevant range of values rather than for a single set of numerical values of these coefficients.

4. Reserve Size and Embargo Length

As it so often happens with mathematical models, the process of formulating the model itself yields insights which may be as important as the ones obtained by solving the model numerically. In the following we discuss one such example.

Sometimes the argument is voiced that a U.S. petroleum stockpile sufficiently large to match the shortfall from an embargo of 6 months might be an incentive for the OAPEC to impose an embargo longer than 6 months. This argument rests upon the naive assumption attributed to the OAPEC, that we would use up our 6 months' stockpile in 6 months rather than spread it over a longer period and use some conservation measures. Beyond this straightforward refutation of the above argument, it can actually be shown

that to the extent that OAPEC objectives are adequately expressed by a function of the general form shown in Figure 3, a larger U.S. stockpile is an incentive for reducing rather than increasing the length of an embargo. Consider two situations, one with a smaller stockpile (#1) and one with a larger stockpile (#2), and assume that an embargo of a given intensity accompanied by a fixed daily cutback in OAPEC petroleum production, is instituted. Both situations are represented in Figure 4. Naturally, in situation 1 the export cutback is accompanied by a greater GNP loss, because of the smaller stockpile; this is expressed in the fact that the slope of the GNP loss curve #1 is sharper than that of the GNP loss curve #2. Accordingly, the function g_1 corresponding to situation 1 takes on higher values than the function g_2 corresponding to situation 2, though both functions are in exactly the same position relative to the corresponding GNP loss functions. Since the cutback in OAPEC petroleum production is not affected by our stockpile, the function h is the same in both cases. Comparing now the two payoff functions for the two situations, $f_1 = g_1 - h$ and $f_2 = g_2 - h$, we see that the maximum of f_2 is to the left of the maximum of f_1 .

5. Some Numerical Results

In order to make full use of the model discussed here, one has to solve the game for all plausible scenarios and all relevant reserve sizes, as well as for all justifiable payoff functions of the two players. This work is currently in progress. Here we illustrate the kind of answers that one can obtain from this model, by analyzing the outcome of the game for some typical cases.

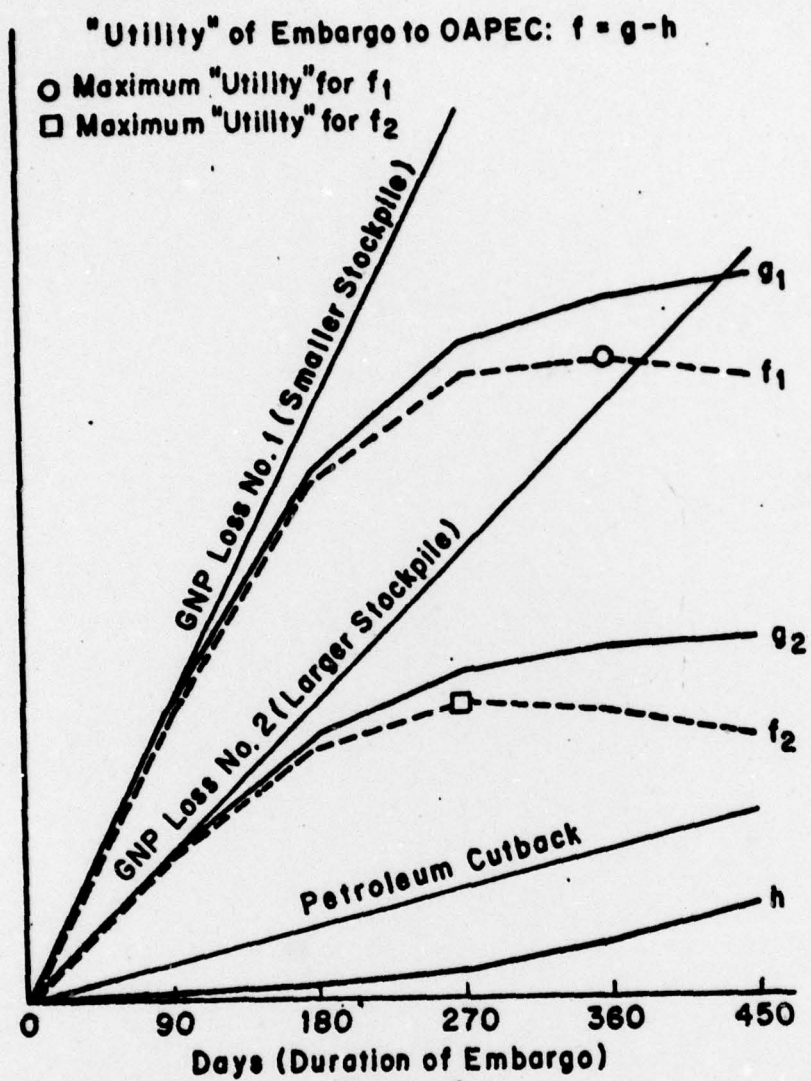


Figure 4

Two conflict situations are considered, in 1981 and 1985 respectively. The OAPEC strategies considered (and shown in Table 1) are potential embargoes of varying length and intensity, corresponding to some of the supply interruption scenarios developed at FEA (for these as well as for other information on the subject, see [2]).

OAPEC Strategy	OAPEC Production Cutback (%)	U.S. Daily Shortfall (MMB)	Duration (days)
<u>1981 case</u>			
1	0 (no embargo)	0	0
2	25	2.5	180
3	25	2.5	360
4	50	3.5	180
5	50	3.5	360
<u>1985 case</u>			
1	0 (no embargo)	0	0
2	25	4.3	180
3	25	4.3	360
4	50	5.5	180
5	50	5.5	360

Table 1

The U.S. strategies are the drawdown policies for the case of an embargo. It is assumed that 3% of the daily petroleum shortfall is taken care of by conservation measures. The remaining supply gap (termed net shortfall) is to be replaced according to the following four strategies.

1. Replace the entire net shortfall for as long as the reserve lasts.
2. Replace the entire net shortfall until the reserve gets depleted to the level of 45 day's net shortfall; thereafter use up every day $1/45$ of the current reserve.
- 3 and 4. Same as 2, with a critical level of 90 and 135 days, respectively.

Strategies 2-4 are called exponential drawdown policies. If α_j is the critical level (in days) defining the j^{th} strategy, strategy 1 can also be represented as an exponential drawdown policy, with $\alpha_1 = 1$.

To generate the OAPEC payoff function $f = g - h$, the quarterly U.S. GNP loss was calculated for each OAPEC strategy and each reserve size, by using an estimator developed by R. Holcombe in his revised study of the economic impact of a petroleum supply interruption (for this estimator as well as other details on embargo-impact calculations, see [4]).

Denoting by L_i the GNP loss in the i^{th} quarter of the embargo, the function g was taken to be $g = L_1 + .8L_2 + .5L_3 + .2L_4$. Further, denoting by V the value of one quarter's OAPEC petroleum exports and by p_i the percentage cut-back in the i^{th} quarter of the embargo, the function h was taken to be of the form $h = .5V[.25(p_1/50)^2 + .5(p_2/50)^2 + .75(p_3/50)^2 + (p_4/50)^2]$.

Naturally, g and h were expressed in the same units (millions of 1975\$, but this is immaterial: the only relevant thing is the relative size of the values of f corresponding to a given stockpile size).

As to the U.S. payoff function, this is the negative of the total cost p (reserve cost plus GNP loss) to the U.S. of the OAPEC action corresponding to each strategy and to each reserve size. The cost of the stockpile was calculated on the basis of a build-up program which starts in 1977 and adds every year up to 200 MMB storage capacity until the target size is reached. The cost of stockpiling consists of \$1.5/B for creating and maintaining the storage facility, and an opportunity cost of \$1.3/B/year (10% of the purchase price of \$13/B) for the money tied up in the stockpile. It is assumed that if the stockpile is used up in an embargo, it is replenished in the year following the embargo. The GNP loss was calculated by using the above mentioned estimator.

The basic difference between the 1981 and the 1985 cases is in the level of the U.S. imports from the OAPEC countries, which puts a limit on the intensity of the embargoes that the OAPEC can impose.

Tables 2 and 3 summarize the outcome of the game for several relevant reserve sizes in 1981 and 1985 respectively.

1981 case

Reserve size	350	475	500
Solutions of the game (equilibrium points)	(5,4)	(3,2)	(1,1),(1,2)
Interpretation:			
Optimal OAPEC strategies	50% cutback 3.5 MMB/day 360 days	25% cutback 2.5 MMB/day 180 days	no embargo
Optimal U.S. strategies	$\alpha_4 = 135$ days	$\alpha_2 = 45$ days	$\alpha_{1,2} = 1-45$ days
Total cost to the U.S. (billions of 1975 dollars, present valued for 1975)	38.63	11.90	2.24

Table 2.

1985 case

Reserve size	500	750	1,000	1,100
Solutions of the game (equilibrium points)	(5,4)	(5,4)	(3,2)	(1,1),(1,2) (1,3),(1,4)
Interpretation:				
Optimal OAPEC strategies	50% cutback 5500 MMB/day 360 days	50% cutback 5500 MMB/day 360 days	25% cutback 4300 MMB/day 180 days	no embargo
Optimal U.S. strategies	$\alpha_4 = 135$	$\alpha_4 = 135$	$\alpha_2 = 45$	any
Total cost to the U.S. (billions of 1975 dollars, 61.58 present valued for 1975)		49.00	15.54	3.24

Table 3.

The most salient feature of Tables 2 and 3 is that in the presence of only a small stockpile, the optimal OAPEC strategy is the heaviest kind of embargo; whereas, in the presence of a large U.S. stockpile, the optimal OAPEC strategy is to have no embargo at all. This expresses the embargo-deterrent effect of a stockpile. The relevant question, of course, is what size of stockpile is sufficient to make an embargo an unlikely strategy to be chosen in case of a conflict situation. In terms of the game, this question reduces to finding the smallest value of the parameter (stockpile size) for which strategy 1 becomes optimal for the OAPEC. In Table 2 this value is 500 MMB whereas in Table 3 it is 1,100 MMB. The main difference between the two situations represented in these tables is in the volume of OAPEC exports to the U.S.A., assumed to be considerably higher (and thus make possible considerably heavier embargoes) in 1985 than in 1981. Obviously, the larger the volume of U.S. imports from the OAPEC countries, the larger the size of the stockpile needed to deter an embargo.

6. Conclusions

Solving the game for several different sets of OAPEC and U.S. strategies and the range of relevant reserve sizes yields the following tentative information on the deterrent effect of the SPR:

<u>Volume of U.S. Imports from OAPEC</u>	<u>Approximate Stockpile Size for Which Embargo Becomes Unattractive</u>
<u>MMB/Day</u>	<u>MMB</u>
2.5-3.5	500-750
3.5-4.5	750-1,000
4.5-6.0	1,000-1,300

The conclusion emerging from this analysis is that the overall size of the Strategic Petroleum Reserve should be the equivalent of 7-8 months' U.S. petroleum imports from the OAPEC countries. If we assume that the total volume of U.S. imports of petroleum products by 1985 will be around 10 MMB per day and that approximately 45% of this amount (i.e., 4.5 MMB/day) will originate with the OAPEC countries, then the optimal size of the Strategic Petroleum Reserve is in the vicinity of the 1,000 million barrels put forward by the Energy Conservation and Policy Act of 1975. If, however, the volume of OAPEC imports will be higher than this amount (a possibility not to be lightly dismissed), then the optimum stockpile size is proportionally larger. Any recommendation for a smaller stockpile size needs to be accompanied by some realistic proposal for keeping the OAPEC imports at a correspondingly lower level.

Further, given the uncertainty surrounding the future level of U.S. imports from the OAPC countries on the one hand, and the relatively low cost of the storage facilities on the other (salt mine leaching plus connecting facilities cost about \$1.5 per barrel), it seems desirable to create a storage capacity well in excess of the contemplated size of the SPR, so as to keep open the possibility for future upward adjustments of the size of SPR in case of an unexpected increase in U.S. imports from the OAPC.

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I wish to thank Harvey Greenberg for inviting me to the Federal Energy Administration, David Nissen for making my visit possible, and both of them for creating the excellent conditions under which I worked. I had many useful discussions on the subject of this paper with Phil Childress, Fred Murphy and others. Last but not least, my thanks go to Marc Sheinberg, whose help was crucial in bringing my project to completion.

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